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THE THERMAL ENVIRONMENT OF THE TERRESTRIAL PLANETS (supplement 3)

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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A new density model of the upper atmosphere of the Earth from 200 to 800 km is presented.

Some physical parameters of the Moon, which are generally those of average silicate rock, have been given by Z. Kopal and are summarized in the paper. If it is assumed that the solar wind has remained unchanged over the period of the moon's existence, the Moon has lost a layer approximately 17 cm thick in $4.5 \cdot 10^9$ years.

A series of model atmospheres for Mars has been developed by Schilling in order to derive upper and lower probable limits for the variation of pressure and density in the upper atmosphere. L. Kaplan estimates the surface pressure to be 20 ± 10 mb, G. P. Kuiper 30 mb.

On the assumption that ordinary meteoritic densities are of the order of 5 g cm^{-3} mean space densities of meteoritic material at the earth's distance from the Sun are found to be of the order of 10^{-21} to 10^{-23} g cm^{-3} . Van de Hulst estimates a total influx of some 10,000 tons per day on the entire Earth

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SPACE THERMODYNAMICS BRANCH

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SUMMARY

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I. VENUS

Mariner II was launched at 1:53 a.m. EST on August 27, 1962 and transmitted for four months, reaching a distance from Venus of approximately 34,835 km on December 14, 1962. The following results are contained in a summary of the Jet Propulsion Laboratory [1].

The rotation rate is estimated as equal to 230 earth days, plus or minus 40 to 50 days. The rotation might be retrograde. Venus has no magnetic field discernible at the distance approached, and at that altitude there are no regions of trapped high-energy particles, as there are near the Earth. The clouds of Venus are about 20 km thick extending from a base 70 km above the surface to a top altitude of about 90 km. At the resolution of the Mariner II infrared radiometer, there were no apparent breaks in the cloud cover. Cloud-top temperature readings are about - 30°C near the center (along the terminator) and ranging down to - 60°C at the limbs. A spot 11°C colder than the surrounding area exists along the terminator in the southern hemisphere. At their base, the clouds are about 93°C. As determined by the microwave radiometer, the surface temperature averages approximately 427°C on both light and dark sides of the planet. The surface pressure is estimated as equal to about 20 bars.

II. EARTH

In Supplement I (MTP-RP-63-5) an upper-atmosphere model was described to calculate the density as a function of the 10.7-cm solar flux S for various local times and altitudes from 200 to 800 km. This model was checked by comparing calculated rates of satellite orbital decay with observed values for seven satellites. This check disclosed a systematic difference for all satellites which was independent of local time and altitude and which arises because S is not an accurate index for the total extreme ultraviolet radiation (EUV). Therefore the following new density model of the upper atmosphere from 200 to 800 km is presented:

$$\rho = K'' S^N$$

N and K'' are given in Tables I and II. It is concluded that the EUV has two variable components, one radiated from active sunspot areas correlated with S, and the other one radiated as a background emission rather uniformly distributed over the entire Sun and not correlated with S. If magnetic-storm conditions are excl ded, the model is essentially correct, provided that S' values as presented in Table III are employed instead of S values. The fact that S' is greater than S only in the interval from February 1958 to March 1961 indicates that the EUV background emission is significant mainly near sunspot maximum. If this is true, then S would be a more accurate index of the total EUV at sunspot minimum than at sunspot maximum [2] .

III. THE MOON

Some physical parameters of the Moon, which are generally those of average silicate rock, have been given by Z. Kopal and are summarized in Table IV [3] .

Different colors have been found indicating a variety of lunar materials. Certain areas have been observed to fluoresce. From time to time short-lived colored spots occur. On October 30, 1963, between 1:30 and 2:15 UT, three reddish orange colored areas were observed near the crater Aristarchus. Another colored spot in the same part of the Moon was observed on November 27, 1963 [4, 5] .

The solar wind blows outward continuously, with a supersonic, nearly constant velocity. For quiet solar conditions, it consists of an average flux of $2 \cdot 10^8$ protons cm^{-2} sec^{-1} with 600 km sec^{-1} average velocity. For solar storm conditions occurring on the average twice per month and lasting $2 \cdot 10^4$ sec, the flux increases by one order of magnitude, and the particle velocity goes up to 1000 km sec^{-1} . Accompanying the protons are 15% α-particles with the same velocities. The effe cts of heavier ions, 0.1% O and C, 10^{-2} % N and Si, 10^{-3} % Mg, S, and Fe, can be neglected in view of their small flux densities. The sputtering rates under solar wind bombardment are summarized in Table V. The combined sputtering rate for Cu is 1.1 Å $year^{-1}$, and for Fe or stones of the order 0.4 Å $year^{-1}$.

TABLE I.

N vs. ALTITUDE AND TIME

Altitude	Local Time (hr)											
(km)	1	2	3	4	5	6	7	8	9	10	11	12
200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
220	1.044	1.046	1.048	1.050	1.052	1.046	1.038	1.033	1.029	1.024	1.020	1.018
240	1.091	1.093	1.095	1.099	1.103	1.093	1.078	1.065	1.061	1.052	1.043	1.036
260	1.122	1.129	1.134	1.141	1.150	1.129	1.103	1.089	1.080	1.072	1.062	1.054
280	1.153	1.162	1.171	1.183	1.195	1.162	1.130	1.110	1.100	1.092	1.081	1.073
300	1.184	1.197	1.209	1.225	1.240	1.197	1.156	1.130	1.119	1.111	1.100	1.091
320	1.216	1.231	1.245	1.265	1.278	1.231	1.187	1.156	1.149	1.142	1.130	1.119
340	1.251	1.265	1.281	1.298	1.315	1.265	1.219	1.190	1.177	1.167	1.152	1.138
360	1.280	1.296	1.310	1.331	1.351	1.296	1.251	1.222	1.206	1.197	1.187	1.174
380	1.310	1.326	1.340	1.361	1.383	1.326	1.278	1.251	1.240	1.225	1.212	1.200
400	1.338	1.355	1.369	1.388	1.412	1.355	1.310	1.280	1.267	1.254	1.242	1.228
450	1.405	1.417	1.432	1.451	1.474	1.417	1.375	1.351	1.338	1.326	1.317	1.303
500	1.459	1.469	1.483	1.501	1.524	1.469	1.437	1.415	1.401	1.390	1.381	1.369
550	1.510	1.518	1.529	1.544	1.564	1.518	1.487	1.469	1.458	1.449	1.441	1.430
600	1.548	1.556	1.567	1.581	1.600	1.556	1.530	1.517	1.507	1.499	1.492	1.483
650	1.581	1.589	1.600	1.613	1.625	1.589	1.568	1.556	1.550	1.542	1.537	1.528
700	1.607	1.614	1.624	1.634	1.644	1.614	1.595	1.587	1.580	1.574	1.569	1.562
750	1.628	1.634	1.642	1.650	1.658	1.634	1.618	1.610	1.605	1.599	1.594	1.588
800	1.645	1.649	1.655	1.661	1.667	1.649	1.636	1.628	1.624	1.619	1.615	1.611

TABLE I
(contd.)

Altitude (km)	Local Time (hr) 13	14	15	16	17	18	19	20	21	22	23	24
200	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
220	1.015	1.010	1.014	1.016	1.019	1.023	1.028	1.030	1.034	1.037	1.040	1.042
240	1.029	1.020	1.024	1.034	1.038	1.048	1.057	1.063	1.070	1.074	1.082	1.087
260	1.045	1.037	1.042	1.051	1.058	1.066	1.077	1.083	1.092	1.099	1.109	1.117
280	1.062	1.053	1.060	1.070	1.077	1.085	1.097	1.104	1.115	1.123	1.134	1.146
300	1.078	1.070	1.074	1.086	1.095	1.103	1.115	1.123	1.138	1.145	1.160	1.174
320	1.103	1.091	1.100	1.111	1.123	1.138	1.145	1.152	1.170	1.180	1.194	1.206
340	1.127	1.119	1.123	1.130	1.145	1.160	1.172	1.184	1.200	1.209	1.225	1.240
360	1.156	1.145	1.149	1.163	1.180	1.194	1.203	1.212	1.231	1.242	1.259	1.270
380	1.184	1.165	1.177	1.194	1.209	1.219	1.231	1.242	1.262	1.275	1.291	1.301
400	1.212	1.200	1.206	1.222	1.237	1.248	1.262	1.273	1.291	1.306	1.320	1.329
450	1.286	1.273	1.278	1.291	1.310	1.320	1.331	1.342	1.361	1.371	1.386	1.398
500	1.355	1.342	1.351	1.361	1.375	1.386	1.396	1.406	1.422	1.432	1.444	1.454
550	1.419	1.406	1.413	1.422	1.435	1.444	1.455	1.464	1.475	1.483	1.492	1.501
600	1.474	1.464	1.469	1.478	1.488	1.496	1.504	1.512	1.520	1.528	1.535	1.541
650	1.520	1.512	1.518	1.524	1.533	1.539	1.545	1.554	1.558	1.563	1.572	1.577
700	1.555	1.548	1.553	1.558	1.565	1.573	1.578	1.583	1.588	1.593	1.598	1.603
750	1.583	1.578	1.581	1.587	1.593	1.598	1.602	1.608	1.612	1.616	1.621	1.625
800	1.606	1.600	1.603	1.609	1.614	1.618	1.622	1.627	1.630	1.634	1.638	1.642

TABLE II.
K" vs. ALTITUDE AND TIME

Altitude (km)	Local Time (hr) 1	2	3	4	5	6	7	8	9	10	11	12
200	1.940(15)[1]	1.930(15)	1.925(15)	1.920(15)	1.910(15)	1.930(15)	1.970(15)	2.000(15)	2.040(15)	2.080(15)	2.100(15)	2.130(15)
220	8.229(16)	8.158(16)	8.088(16)	8.018(16)	8.000(16)	8.158(16)	8.569(16)	8.954(16)	9.294(16)	9.540(16)	9.928(16)	1.038(15)
240	3.964(16)	3.831(16)	3.694(16)	3.601(16)	3.511(16)	3.831(16)	4.194(16)	4.534(16)	4.762(16)	5.005(16)	5.312(16)	5.707(16)
260	2.033(16)	2.002(16)	1.911(16)	1.791(16)	1.690(16)	2.002(16)	2.438(16)	2.714(16)	2.850(16)	3.085(16)	3.232(16)	3.390(16)
280	1.123(16)	1.064(16)	9.839(17)	9.127(17)	8.390(17)	1.064(16)	1.338(16)	1.719(16)	1.873(16)	1.971(16)	2.085(16)	2.232(16)
300	6.247(17)	5.719(17)	5.248(17)	4.826(17)	4.462(17)	5.719(17)	7.429(17)	8.943(17)	1.006(16)	1.091(16)	1.189(16)	1.290(16)
320	3.590(17)	3.250(17)	2.961(17)	2.638(17)	2.453(17)	3.250(17)	4.420(17)	5.466(17)	6.158(17)	6.711(17)	7.467(17)	8.208(17)
340	2.090(17)	1.885(17)	1.683(17)	1.521(17)	1.379(17)	1.885(17)	2.631(17)	3.278(17)	3.660(17)	4.301(17)	4.854(17)	5.451(17)
360	1.270(17)	1.129(17)	1.010(17)	8.807(18)	7.767(18)	1.129(17)	1.550(17)	1.964(17)	2.367(17)	2.701(17)	3.057(17)	3.476(17)
380	7.511(18)	6.616(18)	5.969(18)	5.192(18)	4.454(18)	6.616(18)	9.660(18)	1.237(17)	1.455(17)	1.732(17)	2.026(17)	2.327(17)
400	4.777(18)	4.182(18)	3.722(18)	3.194(18)	2.745(18)	4.182(18)	5.975(18)	7.904(18)	9.524(18)	1.138(17)	1.313(17)	1.550(17)
450	1.366(18)	1.214(18)	1.049(18)	9.011(19)	7.705(19)	1.214(18)	1.848(18)	2.464(18)	3.070(18)	3.836(18)	4.386(18)	5.276(18)
500	4.336(19)	3.817(19)	3.305(19)	2.840(19)	2.388(19)	3.817(19)	5.953(19)	8.347(19)	1.085(18)	1.357(18)	1.627(18)	1.980(18)
550	1.457(19)	1.271(19)	1.101(19)	9.494(20)	7.978(20)	1.271(19)	2.111(19)	3.047(19)	3.989(19)	5.081(19)	6.281(19)	7.767(19)
600	5.233(20)	4.536(20)	3.910(20)	3.349(20)	2.824(20)	4.536(20)	7.889(20)	1.178(19)	1.569(19)	2.038(19)	2.602(19)	3.228(19)
650	2.009(20)	1.737(20)	1.483(20)	1.282(20)	1.082(20)	1.737(20)	3.158(20)	4.809(20)	6.572(20)	8.712(20)	1.137(19)	1.446(19)
700	8.378(21)	7.298(21)	6.172(21)	5.510(21)	3.738(21)	7.298(21)	1.327(20)	2.136(20)	2.965(20)	4.007(20)	5.299(20)	6.767(20)
750	3.946(21)	3.405(21)	2.949(21)	2.595(21)	2.303(21)	3.405(21)	6.538(21)	1.050(20)	1.456(20)	1.922(20)	2.676(20)	3.454(20)
800	2.111(21)	1.832(21)	1.585(21)	1.427(21)	1.275(21)	1.832(21)	3.505(21)	5.654(21)	7.876(21)	1.011(20)	1.495(20)	1.917(20)

[1] Denotes $K'' = 1.940 \times 10^{-15}$ gm watt^{-1} cm^{-1} cps

TABLE II

(contd.)

Altitude	Local Time (hr)											
(km)	13	14	15	16	17	18	19	20	21	22	23	24
200	2.170(15)	2.200(15)	2.180(15)	2.150(15)	2.120(15)	2.090(15)	2.050(15)	2.010(15)	1.990(15)	1.975(15)	1.960(15)	1.950(15)
220	1.087(15)	1.115(15)	1.091(15)	1.064(15)	9.931(16)	9.786(16)	9.535(16)	9.285(16)	8.909(16)	8.658(16)	8.402(16)	8.266(16)
240	5.852(16)	6.199(16)	6.000(16)	5.730(16)	5.452(16)	5.118(16)	4.844(16)	4.635(16)	4.409(16)	4.305(16)	4.100(16)	4.017(16)
260	3.579(16)	3.700(16)	3.563(16)	3.348(16)	3.181(16)	2.972(16)	2.833(16)	2.628(16)	2.468(16)	2.368(16)	2.222(16)	2.095(16)
280	2.249(16)	2.357(16)	2.226(16)	2.083(16)	1.933(16)	1.851(16)	1.686(16)	1.590(16)	1.444(16)	1.371(16)	1.265(16)	1.173(16)
300	1.427(16)	1.478(16)	1.462(16)	1.349(16)	1.237(16)	1.132(16)	1.035(16)	9.581(17)	8.521(17)	8.068(17)	7.251(17)	6.667(17)
320	9.196(17)	9.697(17)	9.383(17)	8.696(17)	7.826(17)	6.832(17)	6.318(17)	5.877(17)	5.107(17)	4.747(17)	4.209(17)	3.874(17)
340	6.086(17)	6.491(17)	6.102(17)	5.818(17)	5.142(17)	4.450(17)	3.957(17)	3.543(17)	3.066(17)	2.860(17)	2.488(17)	2.295(17)
360	4.017(17)	4.296(17)	4.057(17)	3.777(17)	3.242(17)	2.813(17)	2.495(17)	2.211(17)	1.851(17)	1.704(17)	1.482(17)	1.370(17)
380	2.677(17)	2.904(17)	2.695(17)	2.472(17)	2.125(17)	1.845(17)	1.602(17)	1.399(17)	1.133(17)	1.019(17)	8.964(18)	8.347(18)
400	1.819(17)	1.961(17)	1.831(17)	1.655(17)	1.388(17)	1.217(17)	1.042(17)	8.801(18)	7.337(18)	6.524(18)	5.683(18)	5.306(18)
450	6.356(18)	6.968(18)	6.595(18)	5.925(18)	4.776(18)	4.133(18)	3.457(18)	2.845(18)	2.288(18)	1.981(18)	1.687(18)	1.520(18)
500	2.405(18)	2.656(18)	2.498(18)	2.208(18)	1.798(18)	1.532(18)	1.234(18)	9.801(19)	7.959(19)	6.554(19)	5.484(19)	4.863(19)
550	9.516(19)	1.084(18)	1.009(18)	9.001(19)	7.034(19)	5.954(19)	4.603(19)	3.535(19)	2.860(19)	2.362(19)	1.912(19)	1.687(19)
600	4.069(19)	4.593(19)	4.310(19)	3.734(19)	2.943(19)	2.448(19)	1.852(19)	1.379(19)	1.110(19)	8.855(20)	6.952(20)	6.082(20)
650	1.843(19)	2.110(19)	1.961(19)	1.693(19)	1.300(19)	1.072(19)	7.955(20)	5.703(20)	4.609(20)	3.609(20)	2.724(20)	2.354(20)
700	8.836(20)	1.027(19)	9.506(20)	8.133(20)	6.119(20)	4.975(20)	3.574(20)	2.537(20)	2.033(20)	1.547(20)	1.181(20)	1.009(20)
750	4.407(20)	5.406(20)	4.888(20)	4.192(20)	3.148(20)	2.528(20)	1.762(20)	1.229(20)	9.913(21)	7.432(21)	5.605(21)	4.834(21)
800	2.551(20)	3.094(20)	2.730(20)	2.306(20)	1.762(20)	1.424(20)	9.358(21)	6.529(21)	5.326(21)	4.040(21)	3.026(21)	2.626(21)

TABLE III

AVERAGE S' AND S (10^{-22} WATT $m^{-2} cps^{-1}$) BY MONTHS

1958 to 1962

Month	1958		1959		1960		1961		1962	
	S'	S	S'	S	S'	S	S'	S	S'	S
January	–	–	245	271	199	200	110	120	55	93
February	254	210	252	206	181	169	94	105	62	101
March	279	250	256	228	174	146	110	104	73	100
April	322	246	241	210	189	167	92	105	81	96
May	272	219	209	213	147	163	81	99	62	98
June	208	220	184	217	133	162	75	110	55	91
July	212	224	180	203	130	164	78	116	42	81
August	224	237	187	234	153	174	78	106	46	77
September	272	243	207	194	169	164	82	112	65	89
October	286	226	189	164	163	141	79	96	70	87
November	249	207	209	183	160	147	69	89	65	84
December	265	234	189	179	134	136	65	93	56	81
All Months	258	228	212	208	161	161	84	104	61	90

TABLE IV

PHYSICAL PARAMETERS OF THE MOON

Coefficient of Isothermal Compression	=	10^{-12} cm sec^{2} g^{-1}
Coefficient of Viscosity	=	10^{22} g cm^{-1} sec^{-1}
Average Density (min. 3.28, max. 3.41)	=	3.34 g cm^{-3}
Volume Coefficient of Thermal Expansion	=	$2 \cdot 10^{-5}$ ($^{\circ}$K)$^{-1}$
Specific Heat at Constant Pressure	=	$7 \cdot 10^{6}$ erg g^{-1} ($^{\circ}$K)$^{-1}$
Central Pressure	=	$5 \cdot 10^{10}$ dyne cm^{-2}
Average Pressure	=	$2 \cdot 10^{10}$ dyne cm^{-2}
Coefficient of Heat Conduction	=	$2 \cdot 10^{5}$ erg cm^{-1} sec^{-1} ($^{\circ}$K)$^{-1}$
Rate of Energy Liberation Per Unit Mass (due to K^{40}, Th^{232}, U^{235}, U^{238})	=	$2 \cdot 10^{-5}$ erg g^{-1} sec^{1}
Mean Temperature	=	1000°K

TABLE V.

SPUTTERING RATES UNDER SOLAR WIND BOMBARDMENT

Ion	Flux	Velocity	Energy	Yield (atoms/ion normal incidence, smooth surface)	Sputtering atoms cm^{-2} $year^{-1}$	Rate $\mathring{A}$ $year^{-1}$
Proton (solar wind)	$2 \cdot 10^8\ cm^{-2}\ sec^{-1}$	$600\ km\ sec^{-1}$	1850 eV	Cu 0.03	$0.1 \cdot 10^{15}$	0.3
				Fe 0.009	$0.03 \cdot 10^{15}$	0.1
				stony materials		0.1
Proton (solar storm)	$2 \cdot 10^9\ cm^{-2}\ sec^{-1}$	$1000\ km\ sec^{-1}$	5 keV	Cu 0.04	$0.02 \cdot 10^{15}$	0.06
				Fe 0.008	$0.004 \cdot 10^{15}$	0.012
				stony materials		0.012
α - Particle (solar wind)	$0.3 \cdot 10^8\ cm^{-2}\ sec^{-1}$	$600\ km\ sec^{-1}$	7400 eV	Cu 0.04	$0.23 \cdot 10^{15}$	0.7
				Fe 0.25	$0.07 \cdot 10^{15}$	0.21
				stony materials		0.24
α - Particle (solar storm)	$3 \cdot 10^8\ cm^{-2}\ sec^{-1}$ for $\frac{1}{60}$ of time	$1000\ km\ sec^{-1}$	20 keV	Cu 0.2	$0.015 \cdot 10^{15}$	0.045
				Fe 0.06	$0.005 \cdot 10^{15}$	0.015
				stony materials		0.018

If it is assumed that the solar wind has remained unchanged over the period of the moon's existence, the Moon has lost a layer approximately 17 cm thick in $4.5 \cdot 10^9$ years. A major part of the sputtered atoms has ejection velocities which are higher than the escape velocity of the Moon [6] .

Since the composition of the Moon is believed to resemble that of chondrites, the atomic abundances of the elements in chondrites for two groups (high and low in iron content) and the average of all are shown in Table VI , as compiled by Urey and Craig [7] . The average chemical composition of ordinary chondrites is shown in Table VII , according to J. A. Wood.

IV. MARS

A series of model atmospheres for Mars has been developed by Schilling to derive upper and lower probable limits for the variation of pressure and density in the upper atmosphere of Mars amplifying and correcting the work which was discussed in the first issue of this series (MTP-RP-62-7). Three models were selected and labeled as follows:

tentative maximum	-	probable upper limit
tentative standard	-	probable average
tentative minimum	-	probable lower limit

Values of pressure and density of these model atmospheres from the planetary surface to 2700 km are given in Table VIII. The construction parameters are given in Table IX , and the temperatures in Table X [8].

A number of different models have been developed by other authors.

Vertical temperature profiles of several models are shown in Fig. 1. Schilling's conjectural model is the result of comparisons with the earth's atmosphere, in order to obtain the model he considers the most likely to exist. The distinguishing feature of the conjectural model is the existence of a pronounced temperature maximum. The models are summarized in Table XI [9] .

TABLE VI

ATOMIC ABUNDANCES OF THE ELEMENTS IN CHONDRITES

SILICON 10000

Element	Low Iron	High Iron	Δ %	Total Average
Oxygen	34760	33882	-2.6	34386
Sodium	509	490	-3.8	500
Magnesium	9261	9444	+2.0	9335
Aluminum	778	769	-1.2	774
Silicon	10000	10000	—	10000
Phosphorus	47	42	-12.6	45
Sulphur	1000	1100	+10.0	1041
Potassium	58	59	+1.1	58
Calcium	532	595	+12.0	558
Titanium	21	23	+8.8	22
Chromium	87	63	-37.9	76
Manganese	57	54	-6.0	56
Iron	6084	8498	+39.7	7091
Cobalt	17	29	+68.6	23
Nickel	274	476	+73.3	360

TABLE VII

AVERAGE CHEMICAL COMPOSITION OF ORDINARY CHONDRITES

SiO_2	38.29
MgO	23.93
FeO	11.95
Al_2O_3	2.72
CaO	1.90
Na_2O	0.90
K_2O	0.10
Cr_2O	0.37
MnO	0.26
TiO_2	0.11
P_2O_5	0.20
H_2O	0.27
Fe	11.65
Ni	1.34
Co	0.08
P	0.05
Total Silicates	81.00
Total Metals	13.11
FeS	5.89

TABLE VIII

TENTATIVE MODEL ATMOSPHERES

Geometric Altitude (km)	Atmospheric Pressure (mb)			Atmospheric Density (gm cm^{-3})		
	MINIMUM	STANDARD	MAXIMUM	MINIMUM	STANDARD	MAXIMUM
0	4.10×10^{1}	8.50×10^{1}	1.33×10^{2}	7.40×10^{-5}	1.19×10^{-4}	1.49×10^{-4}
2	3.59×10^{1}	7.64×10^{1}	1.21×10^{2}	6.74×10^{-5}	1.10×10^{-4}	1.40×10^{-4}
4	3.13×10^{1}	6.85×10^{1}	1.11×10^{2}	6.11×10^{-5}	1.02×10^{-4}	1.31×10^{-4}
6	2.71×10^{1}	6.12×10^{1}	1.01×10^{2}	5.52×10^{-5}	9.38×10^{-5}	1.22×10^{-4}
8	2.34×10^{1}	5.44×10^{1}	9.17×10^{1}	4.97×10^{-5}	8.63×10^{-5}	1.14×10^{-4}
10	2.00×10^{1}	4.82×10^{1}	8.31×10^{1}	4.45×10^{-5}	7.91×10^{-5}	1.06×10^{-4}
20.1	8.02×10^{0}	2.51×10^{1}	5.04×10^{1}	2.33×10^{-5}	4.66×10^{-5}	6.46×10^{-5}
30.3	2.40×10^{0}	1.18×10^{1}	3.06×10^{1}	8.54×10^{-6}	2.54×10^{-5}	3.92×10^{-5}
40.5	6.68×10^{-1}	5.30×10^{0}	1.86×10^{1}	2.37×10^{-6}	1.14×10^{-5}	2.38×10^{-5}
50.7	1.86×10^{-1}	2.37×10^{0}	1.13×10^{1}	6.60×10^{-7}	5.08×10^{-6}	1.44×10^{-5}
60.0	5.86×10^{-2}	1.15×10^{0}	7.18×10^{0}	2.09×10^{-7}	2.47×10^{-6}	9.20×10^{-6}

TABLE VIII
(contd.)

Geometric Altitude (km)	Atmospheric Pressure (mb)			Atmospheric Density (gm cm^{-3})		
	MINIMUM	STANDARD	MAXIMUM	MINIMUM	STANDARD	MAXIMUM
70.4	1.63×10^{-2}	5.2×10^{-1}	4.37×10^{0}	5.80×10^{-8}	1.10×10^{-6}	5.51×10^{-6}
79.8	5.15×10^{-3}	2.49×10^{-1}	2.83×10^{0}	1.83×10^{-8}	5.34×10^{-7}	3.45×10^{-6}
90.3	1.43×10^{-3}	1.11×10^{-1}	1.78×10^{0}	5.09×10^{-9}	2.39×10^{-7}	2.08×10^{-6}
100	4.9×10^{-4}	5.4×10^{-2}	1.2×10^{0}	1.48×10^{-9}	1.15×10^{-7}	1.34×10^{-6}
120	8.5×10^{-5}	1.2×10^{-2}	5.2×10^{-1}	1.9×10^{-10}	2.5×10^{-8}	5.8×10^{-7}
140	2.3×10^{-5}	2.7×10^{-3}	2.3×10^{-1}	4.0×10^{-11}	5.8×10^{-9}	2.7×10^{-7}
160	8.1×10^{-6}	6.3×10^{-4}	9.0×10^{-2}	1.2×10^{-11}	1.2×10^{-9}	1.3×10^{-7}
180	3.4×10^{-6}	2.1×10^{-4}	2.8×10^{-2}	4.2×10^{-12}	2.9×10^{-10}	5.3×10^{-8}
200	1.6×10^{-6}	9.0×10^{-5}	5.8×10^{-3}	1.7×10^{-12}	1.0×10^{-10}	1.6×10^{-8}
250	3.6×10^{-7}	1.8×10^{-5}	8.6×10^{-5}	3.0×10^{-13}	1.4×10^{-11}	1.1×10^{-10}
300	1.1×10^{-7}	5.6×10^{-6}	1.8×10^{-5}	7.6×10^{-14}	3.5×10^{-12}	1.2×10^{-11}
400	2.0×10^{-8}	3.0×10^{-6}	4.0×10^{-6}	1.0×10^{-14}	5.0×10^{-13}	1.4×10^{-12}

TABLE VIII
(contd.)

Geometric Altitude (km)	Atmospheric Pressure (mb)			Atmospheric Density ($gm\ cm^{-3}$)		
	MINIMUM	STANDARD	MAXIMUM	MINIMUM	STANDARD	MAXIMUM
500	5.8×10^{-9}	3.7×10^{-7}	1.6×10^{-6}	2.3×10^{-15}	1.3×10^{-13}	4.0×10^{-13}
600	2.0×10^{-9}	1.5×10^{-7}	8.5×10^{-7}	7.5×10^{-16}	4.5×10^{-14}	1.8×10^{-13}
700	9.0×10^{-10}	7.0×10^{-8}	5.0×10^{-7}	3.0×10^{-16}	2.0×10^{-14}	9.0×10^{-14}
800	4.0×10^{-10}	3.7×10^{-8}	3.2×10^{-7}	1.2×10^{-16}	9.4×10^{-15}	5.4×10^{-14}
900	1.9×10^{-10}	2.1×10^{-8}	2.1×10^{-7}	5.6×10^{-17}	4.8×10^{-15}	3.3×10^{-14}
1000	1.0×10^{-10}	1.2×10^{-8}	1.5×10^{-7}	2.9×10^{-17}	2.7×10^{-15}	2.1×10^{-14}
1200	3.4×10^{-11}	5.0×10^{-9}	8.2×10^{-8}	8.6×10^{-18}	9.9×10^{-16}	1.0×10^{-14}
1400	1.4×10^{-11}	2.4×10^{-9}	5.1×10^{-8}	3.2×10^{-18}	4.3×10^{-16}	5.8×10^{-15}
1600	6.1×10^{-12}	1.3×10^{-9}	3.4×10^{-8}	1.4×10^{-18}	2.2×10^{-16}	3.5×10^{-15}
1800	2.9×10^{-12}	7.1×10^{-10}	2.4×10^{-8}	6.6×10^{-19}	1.2×10^{-16}	2.3×10^{-15}
2000	1.5×10^{-12}	4.3×10^{-10}	1.8×10^{-8}	3.4×10^{-19}	7.0×10^{-17}	1.6×10^{-15}
2200	8.0×10^{-13}	2.7×10^{-10}	1.4×10^{-8}	1.8×10^{-19}	4.3×10^{-17}	1.2×10^{-15}

TABLE VIII
(contd.)

Geometric Altitude (km)	Atmospheric Pressure (mb)			Atmospheric Density ($gm\ cm^{-3}$)		
	MINIMUM	STANDARD	MAXIMUM	MINIMUM	STANDARD	MAXIMUM
2400	4.5×10^{-13}	1.8×10^{-10}	1.1×10^{-8}	1.0×10^{-19}	2.7×10^{-17}	9.0×10^{-16}
2600	2.6×10^{-13}	1.2×10^{-10}	8.9×10^{-9}	5.9×10^{-20}	1.9×10^{-17}	7.0×10^{-16}
2700	2.0×10^{-13}	1.0×10^{-10}	8.0×10^{-9}	5.0×10^{-20}	1.5×10^{-17}	6.2×10^{-16}

TABLE IX

CONSTRUCTION PARAMETERS

Parameters	Units	Model Atmosphere		
		Tentative Minimum	Tentative Standard	Tentative Maximum
PLANETARY CONSTANTS				
*Effective planetary radius	km	3440	3375	3322
*Effective surface acceleration of gravity	cm sec^{-2}	360	375	390
SURFACE REGION				
*Atmospheric pressure	mb	41.04	85	132.6
Atmospheric density	gm cm^{-3}	7.404×10^{-5}	1.186×10^{-4}	1.489×10^{-4}
*Atmospheric temperature	^{o}K	200	250	300
*Mean molecular mass		30	29	28
Scale height	km	15.4	19.1	22.8
Number density	cm^{-3}	1.487×10^{18}	2.463×10^{18}	3.20×10^{18}

TABLE IX
(contd.)

Parameters	Units	Model Atmosphere		
		Tentative Minimum	Tentative Standard	Tentative Maximum
TROPOPAUSE				
Geometric altitude	km	26.198	30.269	10.030
*Potential height	km	26.000	30.000	10.000
Acceleration of gravity	cm sec^{-2}	354.579	368.363	387.656
Atmospheric temperature	^oK	101.46	162.5	262.86
OZONOPAUSE				
Geometric altitude	km	none	none	61.1—135.3
*Potential height	km			60.0—100.0
MESOPAUSE				
Geometric altitude	km	91.364	150.418	215.078
Potential height	km	89.000	144.000	202.000
Acceleration of gravity	cm sec^{-2}	341.613	343.683	344.013

TABLE IX
(contd.)

Parameters	Units	Model Atmosphere: Tentative Minimum	Model Atmosphere: Tentative Standard	Model Atmosphere: Tentative Maximum
MESOPAUSE (continued)				
*Pressure	mb	1.2595×10^{-3}	1.226×10^{-3}	1.107×10^{-3}
Mass density	gm cm^{-3}	4.479×10^{-9}	2.632×10^{-9}	4.387×10^{-9}
Number density	cm^{-3}	8.99×10^{13}	5.468×10^{13}	9.438×10^{13}
Kinetic temperature	^{o}K	101.46	162.5	84.96
Mean molecular mass		30	29	28
Columnar mass	gm cm^{-2}	3.687×10^{-3}	3.568×10^{-3}	3.217×10^{-3}
Scale height	km	8.23	13.56	7.33
REFERENCE LEVEL ONE				
*Geometric altitude	km	500.000	500.680	500.000
Potential height	km	436.548	436.000	434.589
Gravitational acceleration	cm sec^{-2}	274.427	284.369	294.634
Pressure	mb	5.819×10^{-9}	3.719×10^{-7}	1.649×10^{-6}

TABLE IX
(contd.)

Parameters	Units	Model Atmosphere		
		Tentative Minimum	Tentative Standard	Tentative Maximum
	REFERENCE LEVEL ONE (continued)			
Mass density	gm cm^{-3}	2.317×10^{-15}	1.252×10^{-13}	3.967×10^{-13}
*Molecular scale temperature	^{o}K	906	1035.7	1400
	REFERENCE LEVEL TWO			
*Geometric altitude	km	1500.000	1500.037	1502.531
Potential height	km	1044.534	1038.000	1034.589
Gravitational acceleration	cm sec^{-2}	174.568	179.805	184.907
Pressure	mb	8.974×10^{-12}	1.709×10^{-9}	4.110×10^{-8}
Mass density	gm cm^{-3}	2.025×10^{-18}	2.990×10^{-16}	4.480×10^{-15}
*Molecular scale temperature	^{o}K	1598.8	1993.45	3089.49

TABLE IX
(contd.)

Parameters	Units	Model Atmosphere		
		Tentative Minimum	Tentative Standard	Tentative Maximum
	REFERENCE LEVEL THREE			
Geometric altitude	km	2659.794	2700.000	2734.907
Potential height	km	1500.000	1500.000	1500.000
Gravitational acceleration	cm sec^{-2}	114.496	115.740	117.317
Pressure	mb	2.218×10^{-13}	1.005×10^{-10}	7.898×10^{-9}
Mass density	gm cm^{-3}	5.005×10^{-20}	1.539×10^{-17}	6.045×10^{-16}
***Molecular scale temperature**	^{o}K	1598.8	2278.57	4400

***indicates program input data**

TABLE X

THERMAL STRUCTURE OF MODEL ATMOSPHERES

Potential Height (km)	Molecular Scale Temperature (°K)	Gradient of Molecular Scale Temperature (°K/km)	Representative Kinetic Temperature (°K)	Representative Mean Molecular Mass
TENTATIVE MINIMUM				
0	200	-3.79	200	30
26	101.46	0	101.5	30
89	101.46	+2.315	101.5	30
436.655	906	+1.140	906	30
1044.534	1599	0	906	17
1500.0	1599		906	17
TENTATIVE STANDARD				
0	250	-3.75	250	29
10	212.5	-2.5	212.5	29
30	162.5	0	162.5	29
144	162.5	+2.99	162.5	29
436	1035.714	+1.59	1000.0	28
1038	1993.749	+0.62	1100.00	16
1500	2278.569		1100.00	14
TENTATIVE MAXIMUM				
0	300	-3.714	300	28
10	262.86	0	263	28
60	262.86	+0.51	263	28
70	267.96	+1.1	268	28
100	300.96	0	301	28
130	300.96	-3.0	301	28
202	849.6	+5.65	850	28
434.589	1400.0	+2.82	1100	22
1500	4400.0		1100 2200	7 14

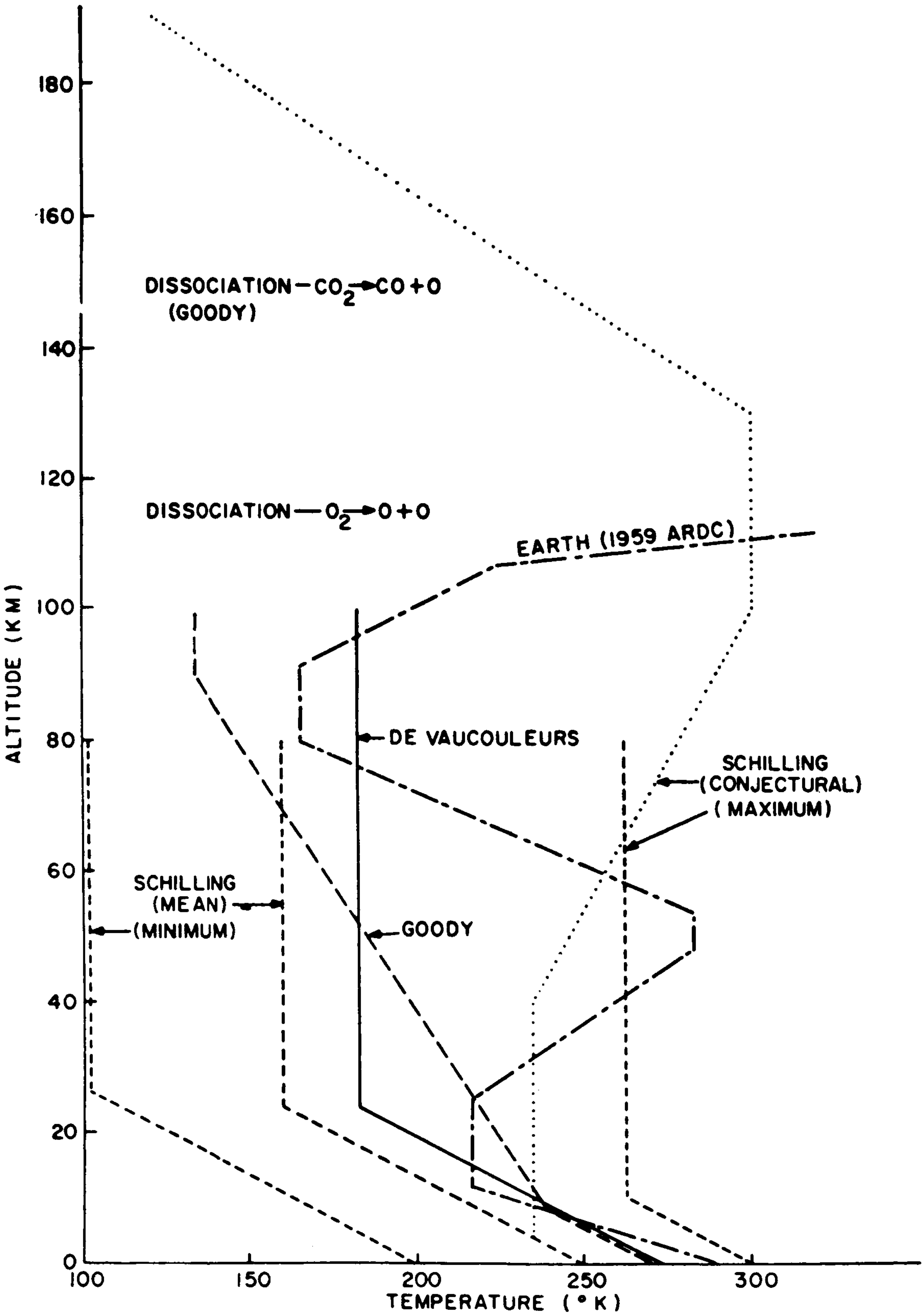

FIGURE 1. VERTICAL TEMPERATURE PROFILES THAT HAVE BEEN PROPOSED FOR THE ATMOSPHERE OF MARS. THE 1959 MODEL OF THE EARTH'S ATMOSPHERE IS INCLUDED FOR COMPARISON.

L. Kaplan estimates the surface pressure of Mars to be 20 $\pm$ 10 mb; G. P. Kuiper estimates 30 mb.

Regarding Kaplan's low value, Schilling makes the following comment:

> "Such an atmosphere, probably consisting mostly of CO_2 and argon, would fall outside of even the lower probable limits derived here. This is a further illustration, if we needed one, that present factual knowledge does not permit us to specify any degree of probability to the present work."

Dollfus believes the clouds to have the following compositions: white clouds–ice crystals; yellow clouds–dust particles 2 to 10 microns in diameter; blue clouds–liquid droplets 2 to 3 microns in diameter; violet layer—an unknown absorbing material. He gives values of 10 to 30 km hr^{-1} for surface winds [10].

From eleven weak lines of water vapor on a high dispersion, near infrared spectrogram of Mars taken with the Mount Wilson 100-inch reflector, it was determined that the Martian water abundance is probably near 5 to 10 microns precipitable water over the Martian poles [11].

V. INTERPLANETARY SPACE

The micrometeorite flux is a thermal parameter, because it influences the emittance of space materials.

The classification of meteors and the methods of study are shown in Table XII according to Whipple and Hawkins [12].

The velocity of escape from the Earth is 11.19 km sec^{-1}, the lowest velocity with which a meteoric body from space can strike the upper atmosphere. The earth's mean orbital velocity about the Sun is 29.80 km sec^{-1}, and the velocity of escape from the Sun, 617.7 km sec^{-1} at the solar surface, corresponds to 42.12 km sec^{-1} at the distance of the Earth. The maximum velocity with which a meteoric body can strike the Earth occurs, therefore, when a meteoroid at its perihelion encounters the Earth head on. Then the velocity

TABLE XI

COMPOSITION AND VERTICAL STRUCTURE OF MARTIAN ATMOSPHERE

Model	Composition % by Volume			Vertical Structure			
	N_2	CO_2	A	Altitude km	Temp. °K	Pressure mb	Lapse Rate Between Indicated Levels, °K km^{-1}
deVancouleurs	93.8	2.2	4.0	0	273	85.0	0-24 km: - 3.75
				24	183	21.4	24-100 km: 0
Schilling(mean)	–	–	–	0	250	85.1	0-24 km: -3.75
				24	160	18.0	24-80 km: 0
Schilling(lower limit)	–	–	–	0	200	41.04	0-26 km: -3.75
				26	101.5	4.01	26-100 km: 0
Schilling(upper limit)	–	–	–	0	300	132.60	0-10 km: -3.75
				10	262.9	37.4	10-100 km: 0
Schilling(conjectural)	–	–	–	0	250	85.1	0-4 km: -3.75
				4	235	68.6	4-40 km: 0
				40	235	9.50	40-100 km: 1.1
				100	301	$5.62 \cdot 10^{-1}$	100-130 km: 0
				130	301	$1.66 \cdot 10^{-1}$	130-180 km: -3.0
				180	151	$1.08 \cdot 10^{-2}$	180-200 km: -3.0
				200	(91)	$1.45 \cdot 10^{-3}$	200- ∞ : —

TABLE XII

METEORITIC PHENOMENA

Class of Bodies	Rough Dimensions	Possible Methods of Detection
Micrometeorites	$< 1\ \mu$	Artificial satellites and rockets
Micrometeorites	1 to 100μ	Light scattering, dust collection, deep sea sediments, artificial satellites, rockets
Faint Meteors	100μ to 0.1 cm	Radio, zodiacal light, artificial satellites
Meteors	0.1 to 10 cm	Photography, radio, visual observation
Fireballs, Bolides	10 to 300 cm	Visual observation, radio
Great Fireballs and Bolides	> 300 cm	Visual observation, radio, craters and geological structures

components total about 72 km sec^{-1} . Atmospheric resistance reduces the velocity. Extremely bright fireballs and detonating bolides undergo reductions to the terminal velocity of free fall, which may be of the order of 1 km sec^{-1} . For micrometeorites these velocities are reduced to negligible values at altitudes of the order of 100 km above the earth's surface.

On the assumption that ordinary meteoritic densities are of the order of 5 g cm^{-3} , mean space densities of meteoritic material at the earth's distance from the Sun are found to be of the order of 10^{-21} to 10^{-23} g cm^{-3} . Van de Hulst estimates a total influx of some 10, 000 tons per day on the entire Earth.

REFERENCES

1. Wheelock, H. J. (ed), Mariner, Mission to Venus, McGraw-Hill Book Co., New York-San Francisco-Toronto-London, 1963.

2. Anderson, A. D., "On the Inexactness of the 10.7 cm Flux from the Sun as an Index of the Total Extreme Ultraviolet Radiation," Journal of Atmospheric Science, 21, to be published in 1964.

3. Kopal, Z., "Thermal History of the Moon and of the Terrestrial Planets," JPL Technical Report No. 32-276, 1962.

4. Greenacre, A., Sky and Telescope, 26, p. 316-317, 1963.

5. Editorial, Sky and Telescope, 27, p. 3, 1964.

6. Wehner, G. K., Kenknight, C., and Rosenberg, D. L., Planet Space Science, 11, 885-895, 1963.

7. Fluegge, S. (ed), Encyclopedia of Physics, 52, Springer-Verlag, Berlin-Goettingen-Heidelberg, 1959.

8. Schilling, G. F., Parametric Limits for the Upper Atmosphere of Mars, Rand Corp. Memorandum RM-3885-PR, 1963.

9. Coulson, K. L. and Lotman, M., "Molecular Scattering of Solar Radiation in the Atmosphere of Mars," Journ. of Geophys. Res. 68, pp. 5681-5688, 1963.

10. Coulson, K. L., Trip Report on Colloquium on Atmosphere of Mars, NASA Hqs., October 1, 1963.

11. Spinrad, H., Muench, G., and Kaplan, L. D., Astrophys. Journ. 137, pp. 1319-1321, 1963.

12. Middlehurst, B. M. and Kuiper, G. P., The Moon Meteorites and Comets, University of Chicago Press, Chicago and London, 1963.

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THE THERMAL ENVIRONMENT OF THE
TERRESTRIAL PLANETS
(Supplement 3)

(By Klaus Schocken)

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